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From bench to bedside: does a human-sized MPI scanner work with endoprosthesis of the hip and knee?

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Abstract

In the last years, MPI hardware has been scaled-up for clinical size especially for brain and head imaging. Recently, a human-sized leg scanner dedicated for intervention has been presented providing real-time imaging. In a first study, the influence of metallic endoprosthesis on MPI functionality in a human-sized MPI scanner has been investigated. No relevant impairment of imaging from the presence of endoprosthesis could be found.

I. Introduction

Peripheral arterial disease (PAD) is a widespread illness with significant impact on public health [1]. Patients suffering from PAD have atherosclerotic narrowing of leg arteries causing ischemia, pain and subsequent limb loss if not treated early on. Endovascular interventions using X-ray digital subtraction angiography are a mainstay of PAD therapy. In those respects, it is a considerable contributor to civilisatory radiation exposure to both operators and patients. Vascular interventions of the leg in PAD contribute a lions-share of radiation exposure to both, operators and patients [2]. Also, both, the necessity for intervention and the rate of endoprosthesis carriers rises with age.

Magnetic Particle Imaging (MPI) is a rapidly evolving tool promising radiation free tracer-based imaging with high spatial and temporal resolution [3-5]. Recent scanner models intended for vascular interventions have come down in size and complexity so far, that actual application in humans is a tangible opportunity [6]. To be applicable in real world scenarios, scanners must be able to cope with a variety of obstacles. Many patients eligible for angiography carry metallic endoprosthesis of significant size, such as total endoprosthesis of the hip and knee.

The aim of this study was to investigate the influence of metallic endoprosthesis on MPI functionality in a human-sized MPI scanner for vascular interventions of the leg.

II. Material and methods

To investigate the influence of artificial materials within an MPI scanner and potential impacts on the image quality, a racetrack phantom filled with Perimag® (micromod, GmbH, Germany with 25 mg/ml iron concentration) is used as image reference to visualize possible distortions and influences by artificial materials. The phantom is aligned parallelly along the main axis of the scanner (z-axis).

Figure 1: Top left: human-sized iMPI scanner for vascular intervention of the leg. Top right: photo of the experimental setup for investigating the influence of endoprosthesis on the image quality. Bottom: images of different endoprosthesis of the hip and knee.

II.I. Human-sized MPI scanner

The interventional human-sized MPI scanner (iMPI) provides rapid projection imaging with a field of view (FOV) of about 20×25 cm² (6). The generated field-free line (FFL) with a gradient strength of about 0.4 T/m is steered on a sinusoidal trajectory through the FOV with frequencies f_1=60 Hz and f_2=2,480 Hz. Each image has been acquired within 50 ms and reconstructed using image-based system matrix approach [7, 8]. The system matrix for the reconstruction has a size of 35×81 voxels with a distance of 3 mm covering a projection FOV of 10.5×24.3 cm². For reconstruction, an iterative Kaczmarz algorithm (100 iterations, λ=0.1) has been used.

II.II. Imaging protocol

Different protocols for signal and image investigation were performed:

1. **empty measurements:** no load within the scanner. This experiment is used for determining the baseline signal of the scanner.
2. **reference measurements:** imaging experiment with racetrack Perimag® phantom. This experiment provides the ground-truth images without any additional artificial materials.
3. **loaded measurements:** imaging experiment with given endoprosthesis at different positions and under different angles. This experiment is used to figure out if there is any influence on the receive chain.

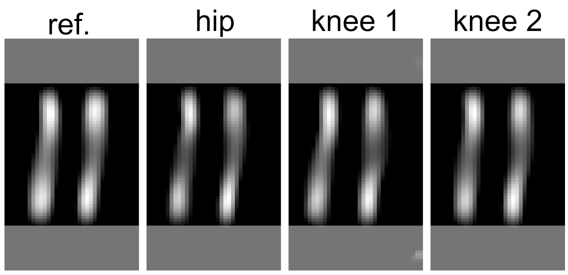

Figure 2: Reconstructed images of a racetrack phantom filled with Perimag® without (ref) and with endoprosthesis for hip and knee.

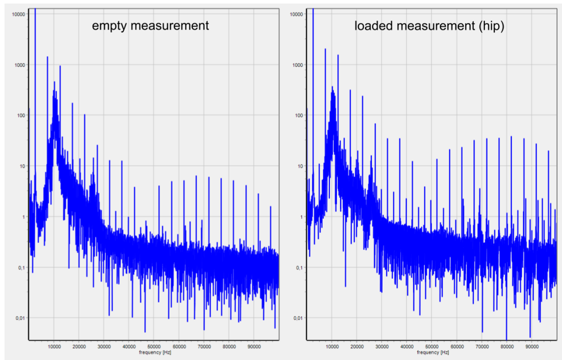

Figure 3: Raw spectra of an empty measurement (left) and for an experiment loaded with the hip endoprosthesis sample (right).

4. **imaging measurements:** imaging experiment with both, reference Perimag® sample and endoprosthesis. As indicated in Fig. 1 top right, the endoprosthesis samples have been placed directly above the racetrack sample.

II.III. Endoprosthesis

For studying possible influences of endoprosthesis on the image quality within an iMPI scanner, two different types of endoprosthesis have been used (see Fig. 1 bottom).

1. One total endoprosthesis of the hip (***hip***) (Allofit-S Alloclassic; Zimmer GmbH; Switzerland). Main material components: chromium, cobalt, molybdenium, nickel, polyethylene, and ceramic.
2. Two different types of total endoprosthesis of the knee (***knee 1*** and ***knee 2***) (Zimmer Biomet Deutschland GmbH; Germany). Main material components: stainless steel alloy from chromium, cobalt, molybdenium, polyethylene.

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III. Results

The reconstructions in Fig. 2 show the result of the imaging measurement within a human-sized MPI scanner with and without endoprosthesis. The reference image (Fig. 2: ref.) clearly show the two parallelly parts inside the FOV of the racetrack phantom filled with Perimag®. The reconstructed images with hip and knee endoprosthesis are provided on the right side and show no visual influence on the image quality.

In Fig. 3, example raw spectra (no filtering, no receive chain correction) are shown for an empty measure (Fig. 3 left) and for a loaded experiment with hip endoprosthesis sample.

Clearly an increase of the higher harmonic magnitudes generated by the amplifiers can be observed, but no frequency mi-xing higher harmonics.

IV. Discussion

As indicated in Fig. 2, the influence of endoprosthesis on the image quality within human-sized MPI scanner is negligible. However, with increasing gradient, a stronger field distortion is expected, which may have influence on the image quality.

In addition, the presence of solid materials within the receive coil is clearly visible in the signal spectrum due to loading. This effect can be suppressed by prior empty measurement similar to gold standard methods DSA (digital subtraction angiography).

An open question could be the heating effect through the time-varying magnetic fields. During this study, no heating of the samples could be observed. However, since the scanning time was in the range of less than 10 seconds, this effect has to be investigated for longer exposure times.

V. Conclusions

Being a projection technique, digital subtraction angiography of the lower limbs suffers reduced feasibility in cases, when metal is in the field of view. Additionally, a massive increase in radiation dose due to exposure compensation of x-ray tubes, can be the consequence. If those solid metallic objects would not disturb MPI use, the technology would be eligible for a major proportion of patients, which might be a major upside of the technology itself and promote its advancement to a serious alternative for X-ray.

We could demonstrate that imaging acquired with human-sized MPI scanner showed no relevant impairment from the presence of endoprosthesis. These results constitute MPI as a promising alternative in the future and encourage further investigations.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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